How to Assess the Global Environmental Impacts Caused by a National Economy?

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Abstract

Environmentally extended input-output (EE-IO) tables offer a basis to assess all materials flows in an economy and domestic environmental interventions (emissions, raw material extractions, land use). Furthermore, it is possible to assess environmental interventions for the imported materials, by for example using life cycle inventory databases. The impact assessment methods used in the EE-IO models are commonly based on site-generic characterisation factors of life cycle impact assessment (LCIA). The paper addresses a new procedure to assess global environmental impacts using a site-specific approach. First, the most important material flows and their import countries were identified. Second, the state of the environmental problems in each continent was identified using literature. Third, this information with Europe-specific characterisation factors was utilized by an expert panel in which area-specific characterisation factors were determined. Finally, all environmental interventions occurring in each area were multiplied by the corresponding area-specific characterisation factors. The assessment method was tested in the case of the Finnish EE-IO application. The site-specific impact results of regional and local environmental impact categories (e.g. acidification, particulate matter) related to materials imported from outside Finland differ dramatically from the results derived by commonly used site-generic characterisation factors.

Keywords: Environmentally extended input output model, Characterisation, Life cycle impacts assessment, LCIA, Global environmental impacts.

1. Introduction

Both natural resource consumption and gross domestic product (GDP) have increased in the Finnish economy during the last few decades. A similar trend can be seen in other developed countries (EEA 2003). However, a study carried out by Bringezu (2002) shows that the relationship between the Total Material Requirements (TMR) and the GDP of the Finnish Economy is different from that of many other countries. TMR is an indicator of natural resource consumption describing all direct and indirect material flows (so-called "hidden" flows) associated with imports and domestic extraction (e.g. European Commission 2001). In Finland the growth of TMR has been exceptionally high compared with other developed economies, which is mostly attributable to the raw material extractions by the Finnish metal and forestry industries. This has sparked a debate among Finnish environmental administrators and political decision makers, leading to a question within Finland: what are the environmental impacts of the Finnish economy abroad?

It was against this background that an extensive R&D project, Environmental Impacts of Material Flows Caused by the Finnish Economy (ENVIMAT), was started in spring 2006 as part of the Finnish Environmental Cluster Research Programme 2006-2009 in order to assess life cycle environmental impacts caused by production and consumption within the Finnish economy. This paper addresses the impact assessment methodology for assessing environmental impacts caused by domestic activities and activities abroad that are related to Finnish materials and energy flows. With this, it is hoped that material will be created for a discussion about best practices in the global impact assessment of a national economy.

2. Materials and methods

2.1 Finnish environmentally extended input-output model

In the ENVIMAT project the aim was to create an advanced model for assessing the environmental impacts of the Finnish economy. For this purpose, the monetary input-output tables of Statistics Finland and the physical flow accounts for the Finnish economy conducted by Mäenpää (2005) offered a starting point for methodological development. The tables including 151 industry sectors and 925 products cover the following main physical accounts for Finland: raw materials, unused extraction, products, residuals, indirect inputs of imports.

In the inventory phase of the ENVIMAT project the tables for the physical flow accounts have been completed with new environmental data from the situation in 2002 (and in 2005 at the end of 2008). Domestic environmental interventions (emissions, raw material extractions and land use) were assessed using a national emission register (called VAHTI), the Finnish air pollutant inventories (calculated by national as well as the EMEP/CORINAIR guidebook methods) and other official Finnish statistics. For imports there were four different alternative datasets (for the more detailed description of the alternatives see Koskela et al. 2008). The basic dataset for imports consisted of data derived from the Ecoinvent database (2008), Danish LCA Food Database (2008) and domestic data. This data set was used for the calculations in this study.

Finally, life cycle based environmental impact assessment tools were combined with the input-output framework. The impact assessment included the following environmental impact categories: 1) climate change, 2) ozone depletion, 3) acidification, 4) tropospheric ozone formation (impacts on human health and vegetation) 5) aquatic eutrophication, 6) terrestrial eutrophication, 7) particulate matter 8) ecotoxicity, 9) human toxicity, 10) depletion of natural resources and 11) impacts on biodiversity.

Indicator results for the impact categories were assessed by so-called midpoint methods. In characterisation both site-generic and site-specific factors were used. For the calculations of acidification (Seppälä et al. 2006), tropospheric ozone formation (Hauschild et al. 2004), aquatic eutrophication (Seppälä et al. 2004), terrestrial eutrophication (Seppälä et al. 2006) and particulate matter (van Zelm et al. 2007, Krewitt et al. 2002) site-specific characterisation factors were applied. The assessment of impacts on biodiversity was based on the information about major threats to endangered species published in the so-called publications of Red List of Species (Committee for the Monitoring of Threatened Species in Finland 2001). Characterisation factors for abiotic resource depletion were obtained from the old CML method (Guinée et al. 2002). Characterisation factors for the other impact categories corresponded to site-generic factors used in the method set of Sleeswijk et al. (2007).

2.2 Impact assessment procedure used

In the site-specific impact assessment, the environmental impacts caused by domestic activities in Finland were calculated using Finland-specific characterisation factors for acidification, tropospheric ozone formation, aquatic eutrophication, terrestrial eutrophication, particulate matter and impacts on biodiversity. In the domestic case, the characterisation factors of ecotoxicity and human toxicity corresponded to site-generic factors because of a lack of Finnish-specific factors.

The aim was to apply consistent characterisation factors for the environmental interventions of domestic activities and imports. For this reason, the bases of characterisation factors within each impact category should be the same. This could be done for European countries in acidification, tropospheric ozone formation, aquatic eutrophication, terrestrial eutrophication and particulate matter because European country-dependent characterisation factors could be found for the impact categories. However, the situation is different if the environmental interventions occur outside of Europe. This is also the case for the other regional and local impact categories (ecotoxicity, human toxicity, impacts on biodiversity) to which there are no site-specific characterisation factors at all.

The first step to find characterisation factors for imports was to identify countries from where the main material flows were imported. On the basis of this analysis the product group data were arranged according to different continents and countries.

The second step was to identify the state of the environmental problems in different continents using literature. The starting point was to compare the state of areas (countries or part of continents) with the state of Europe. Thirdly, this information with Europe-specific characterisation factors was utilized by an expert panel in which continent- or country-specific characterisation factors were determined. Fourthly, all environmental interventions occurring in each area were multiplied by the corresponding site-specific characterisation factors.

To assess the role of the site-specific approach the alternative calculations for the environmental impacts of imports were carried out. In the first alternative calculations, characterisation factors of imports corresponded to the site-specific factors used for domestic activities. In the second case, the calculations for domestic activities and imports were calculated using the same site-generic characterisation factors of the updated CML method (Sleeswijk et al. (2007)).

In the presentation of the results, indicator values within each impact category were divided by the corresponding indicator value of domestic activities. Thus, the domestic results were normalized to 1, whereas the results of imports varies below or above 1. In this way the results could be presented in the compact way.

3. Results and discussion

In terms of quantity the greatest material flows imported to Finland originated from Russia and European countries. They covered over 90 percent of the total imported materials in 2002. At the top of material flows are wood (pulp wood, logs), fossil fuels (oil, coal, natural gas) and ores/concentrates (e.g. iron ore) (Table 1).

Table 1.

The site-specific impact assessment for imports could be kept relatively simple due to the clear picture about the import countries. Russia-specific characterisation factors were used for the material flows originating from Russia. However, the factors are missing in aquatic eutrophication, ozone formation and particulate matter. For this reason, in these cases Finland-specific characterisation factors were used because of the similar environmental conditions in Finland and Northern Russia.

If there was no dominant import country for a product group imported from Europe, we used European average characterisation factors for the product group. In the case of a dominant import country we used country-specific characterisation factors (e.g. Denmark-specific characterisation factors for foodstuffs).

In the material flows imported from outside of Europe, we used European average characterisation factors. We used this rough assumption due to the relatively small share of total imports. On the other hand, so-called nonferrous metal ores (e.g. copper, nickel, zinc) originated form countries outside Europe (e.g. Chile, Australia), and it was well-known that there was a need to trace their real product chain in order to assess their true toxicity and other regional environmental impacts. However, it was not possible to do this during this project because of the limited resources.

In the context of aquatic eutrophication, the site-generic characterisation factors were used for all countries except Russia and the countries around the Baltic Sea. For the category of human toxicity, it was assumed that Finland-specific characterisation factors are also applicable to Northern Europe and Russia. Finland-specific characterisation factors for human toxicity were derived from original site-generic characterisation factors on the basis of the differences between human exposure, based on population density which is 17 inhabitants per km^2 in Finland and 70 inhabitants per km^2 averaged across the rest of Europe. In the case of ecotoxicity, knowledge among the project team was insufficient to apply site-specific characterisation factors for imports. In addition, impacts on biodiversity per material extractions were assumed to be same in Finland as aboard.

During the process, the members of the project group gathered data regarding global situations in environmental problems (e.g. the deletion of biodiversity). On the basis of this information and based on the imports, attempts were made too identify the material flows causing great impacts outside of Europe. The analysis did not reveal any significant material flows. Exceptions were nonferrous metal ores and concentrates. However, detailed analysis was not completed for these flows due to the reasons mentioned above.

The site-specific approach produced quite a different overview about the impact category indicator results of imports compared with the situation in which only site-generic characterisation factors were used (Figures 1 and 2).

Based on an analysis, the great differences between the results of domestic activities and imports can be observed in human toxicity and particulate matters depending on how to the site-specific approach is applied to the imports. Note that the first calculation for the imports (Imports 1 in Figure 1) means that it was assumed that environmental interventions caused by imports have the same impact on the environment as the domestic activities have. The alternative assumption (Import 2) leads to a different view about the environmental impacts of imports.

Note that the characterisation results of the site-generic approach (Figure 2) offers very similar results as the calculations in Figure 1 in which the same site-specific characterisation factors for domestic activities and imports were used (Domestic and Import 1 in Figure 1). The exception is tropospheric ozone formation in which the results differ between the two approaches.

Figure 1.

Figure 2.

The differences between domestic activities and imports were greatest in the contexts of aquatic ecotoxicity, human toxicity and particulate matters. The large toxicity values of the import were mostly due to the few metal emissions (e.g. nickel, zinc) of imported nonferrous metal ores and concentrates. The question arises: the inventory data and the assessment methods for toxicity in which the metals play a very important role be trusted? It is a well known feature that metals are not well described in the current LCIA methods (e.g. Dubreuil 2005).

4. Conclusions and future outlook

Impact assessment methods used in the environmentally extended input output (EE-IO) models are commonly based on site-generic characterisation factors of life cycle impact assessment (LCIA). However, this study has shown that the site-specific approaches can offer a very different view about the environmental impacts of regional and global environmental problems caused by a national economy compared with the situation in which only site-generic characterisation factors are used.

The site-specific assessment procedure presented in this study was applied roughly and the inventory data could still include errors. For this reason, the results should be considered as preliminary. In the future, a more detailed procedure is needed.. Metal ores and concentrates especially should be assessed more precisely. This requires both better environmental data on real product chains and better impact assessment tools, in particular, for toxicity issues.

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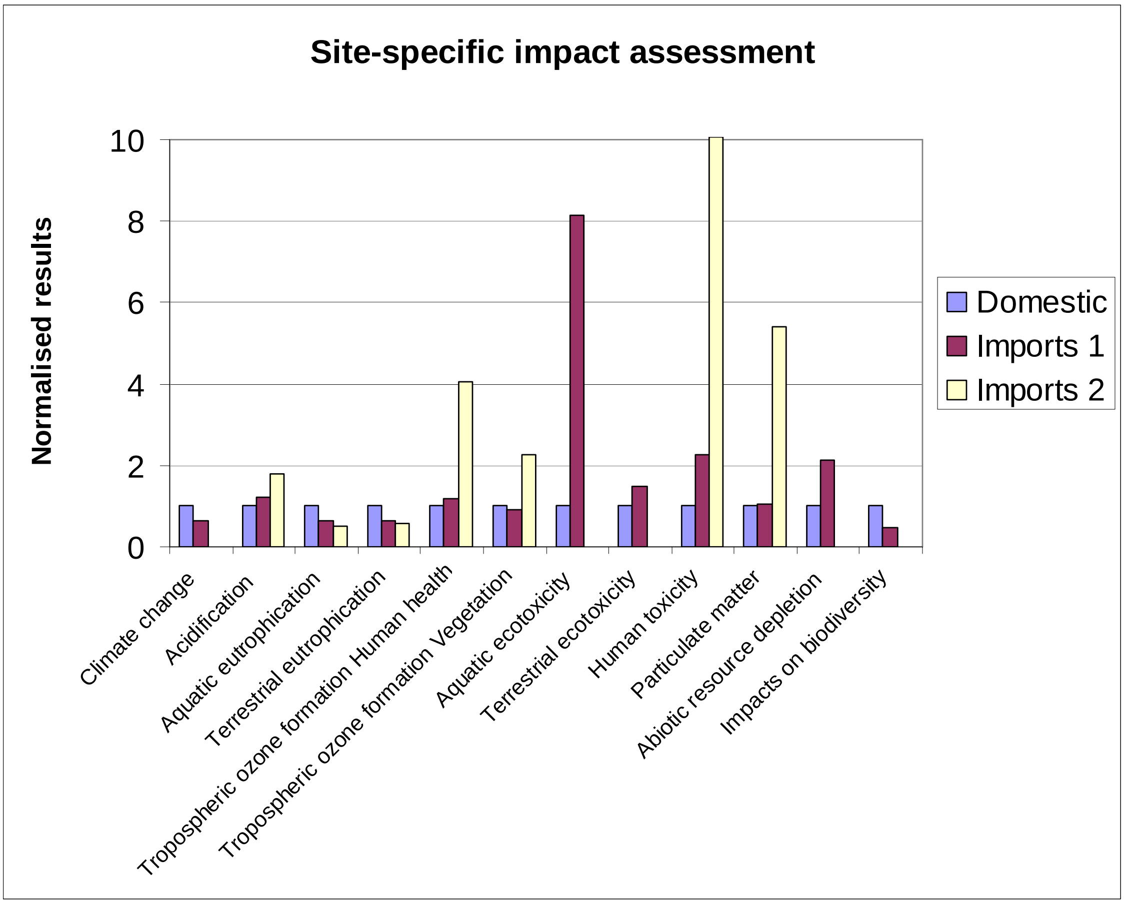

Figure 1. Normalised impact category indicator results for domestic activities and imports calculated using the site-specific impact assessment method with two alternative characterisations for imports: Imports 1 = same characterisation factors for domestic activities and imports, Imports 2 = site-specific characterisation factors for imports based on the assessment procedure. (The normalisation in this case means that category indicator results within each impact category were divided by the corresponding indicator value of domestic activities).

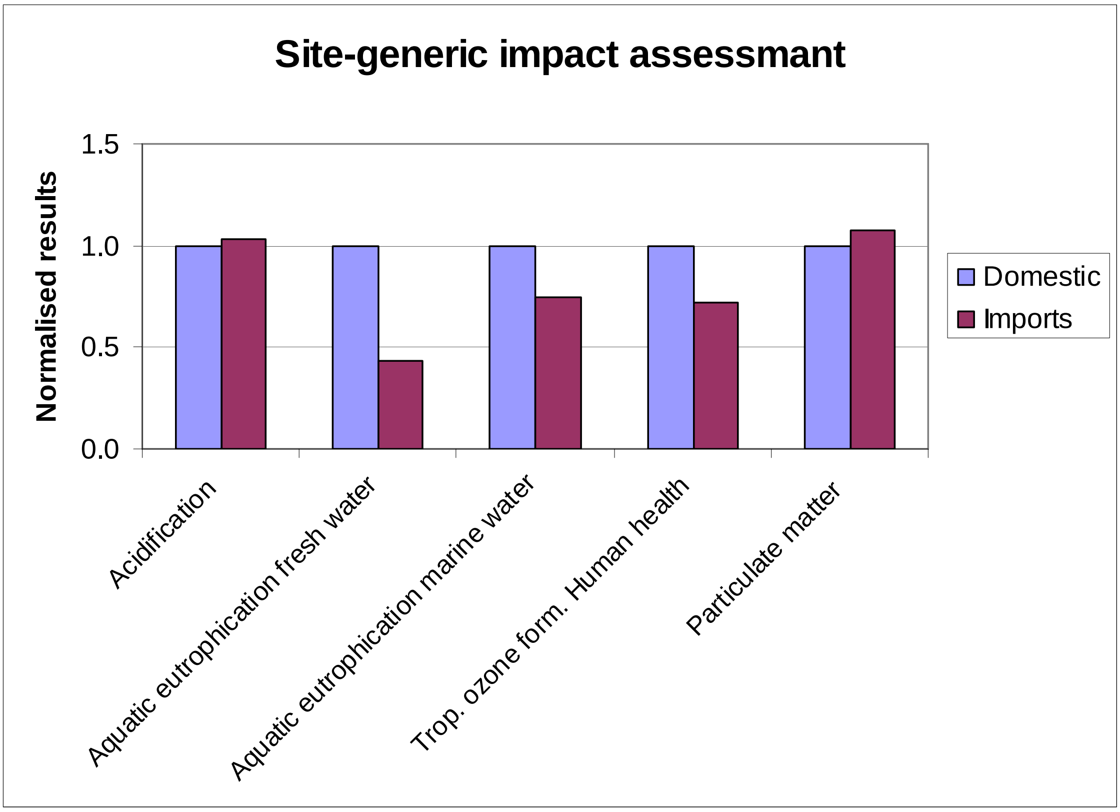

Figure 2. Normalised environmental impact category indicator results for domestic activities and imports calculated using the site-generic impact assessment method. The calculations were only made for impact categories for which site-specific characterisation factors have been applied in Figure 1. Note that terrestrial eutrophication is missing and aquatic eutrophication is dived into two sub-categories in the method set of Sleeswijk et al. (2007). Furthermore, the tropospheric ozone formation only represents the respiratory effects of human health. The normalisation in this case means that category indicator results within each impact category were divided by the corresponding indicator value of domestic activities).

Table 1. Top 16 material flows imported to Finland in 2002 and their source areas with the share of the total imports.

Product	Amount (1000 tn)	Share of the total imports (%)		
		Russia	Rest of Europe	Other countries
Pulpwood	13,576	86.5	11.7	1.8
Petroleum oils	11,756	53.4	41.1	5.5
Coal	5,789	45.6	33.7	20.7
Iron ores	3,779	27.8	69.4	2.8
Natural gas, liquefied or in gaseous state	3,149	100	0.0	0.0
Light fuel oils	2,541	21.7	78.2	0.1
Limestone and gypsum	1,870	99.9	0.1	0.01
Logs	3,957	89.1	10.9	0.01
Heavy fuel oils	1,797	21.7	78.1	0.2
Other basic organic chemicals	1,286	62.4	35.1	2.5
Clays and kaolin	1,264	9.3	47.7	43.0
Other basic inorganic chemicals	1,214	1.8	97.2	1.0
Plastics in primary forms	534	3.1	93.1	3.8
Kerosene, including kerosene type jet fuel	514	0.0	60.2	39.8
Copper ores and concentrates	501	14.5	85.5	0.0
Slag and dross, ferrous waste and scrap, remelted scrap ingots	491	65.3	33.5	1.2